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HYBRID ELECTROTECHNOLOGIES : RADIOFREQUENCY/AIR-JET IMPINGEMENT

B.G. Woods and S.J. Oda

A prototype radiofrequency/air-jet impingement hybrid was designed and constructed to compare the drying and heat transfer characteristics of three systems: air-jet impingement, radiofrequency heating, and the combination of air-jet impingement with radiofrequency heating. The results from preliminary tests performed on the prototype indicate that the effectiveness of the hybrid is very sensitive to process parameters such as air temperature. Therefore a demonstration unit will play an important role in optimizing similar hybrid processes for industrial customers. The results also show that further development should involve improvements to the performance of the air-jet impingement system.

INTRODUCTION

Hybrid electrotechnologies involve combinations of technologies which are used to improve the effectiveness of a process. By adjusting the balance between the technologies, it is possible to optimize the process in terms of the process effectiveness and cost. A general review (ref. 6) has been prepared on the potential for combining dielectric heating with other technologies. Also, a list of existing and potential applications of dielectric heating hybrids was prepared in a memo to Mr. M.R. Sanio (May 19, 1989, file 814.35) and is included in Appendix I. The work described in this report follows up the initial reviews, by testing a radiofrequency and air-jet impingement hybrid. Ultimately, the results from this and further work could be incorporated by Canadian manufacturers, into their drying and heating equipment.

Radiofrequency and air-jet impingement technologies are particularly well suited to each other in a hybrid process, as radiofrequency energy provides high heat transfer rates within the product and air-jet impingement provides high transfer rates (mass and heat) at the product surface.

At the request of Mr. M.R. Sanio, air-jet nozzles were added to an existing radiofrequency dryer/heater for the purpose of comparing the drying and heating characteristics of the two technologies. This required designing, constructing and installing the air-jet impingement nozzles, making alterations to the radiofrequency equipment for the sake of compatibility and performing preliminary tests on the hybrid

job	file	date	report no.
12-129	814.35	December 21, 1990	90-311-K

system. The nozzles were designed according to guidelines in published literature (described in Appendix II) for optimizing heat transfer and drying rates. There are also air nozzles commercially available which may be effective in the hybrid system, and could be tested in subsequent work.

The two types of preliminary tests performed on the hybrid system were heat transfer and mass transfer (drying) tests. The procedures used in these tests are described in Appendix III. It is important to note that more work will be required to optimize the performance of the air-jet impingement system, and therefore the preliminary results may not be representative of an optimized radiofrequency and air-jet impingement hybrid system.

RESULTS FROM THE PRELIMINARY TESTS

The results from the drying tests are shown in Figures 1 and 2. The figures show the moisture content of a 0.006 m x 0.914 m x 0.61 m (1/4" x 3' x 2') piece of particle board after passing it through the hybrid. Each pass represents approximately 30 s of process time in the hybrid. From the shapes of the plots in Figure 1, it can be seen that the air-jet impingement with room temperature air, had very little impact on the drying. In the tests with the hybrid, the air-jet impingement with room temperature air actually had a negative effect on the drying rate. The negative effect on the drying rate may be occurring because the air-jet is cooling the sample, and thus offsetting some of the radiofrequency heating. However, when the air was heated to 70°C (results in Figure 2), the air-jet impingement had a significant positive effect on the drying rate.

The results from the heating tests indicate that the heated air-jet had very little effect on the transfer of heat to the sample (see Figure 3). The low heat transfer rate is likely due to the fact that, although the air-jet was 70°C, the average air temperature around the sample was between 30°C and 35°C. The thermal properties of the sample used (ie. neoprene) could also have been an important factor in the low rate of heat transfer.

The results from the tests performed to commission the hybrid (tests described in Appendix II) show that by altering the nozzle spacing (or number of nozzles used) and the nozzle diameter, the drying rate was nearly doubled from the initial nozzle configuration.

CONCLUSIONS

The performance of the air-jet impingement system is sensitive to even small changes to the nozzle design and therefore significant performance improvements could likely be obtained by further optimizing the design of the nozzles.

The effectiveness of the hybrid tested is very sensitive to process parameters such as air temperature. Therefore, a demonstration unit could play an important role in minimizing the electricity consumption of similar hybrid processes for industrial customers.

RECOMMENDATIONS

It is recommended that further development be performed to improve the performance of the nozzles in the air-jet impingement system. Improved nozzle performance would improve the performance of the hybrid system. It would also fit into the broader category of increasing the efficiency of convection drying and heat transfer in industrial processes.

Some specific recommendations on the development of air-jet impingement systems (all of which would likely be performed on a small scale) are :

1) test the relative performance of commercially available nozzles in the air-jet impingement system,

2) test some performance enhancing techniques for air-jet impingement, such as using screens to create free stream turbulence in the air-jet (some techniques described in reference 4), and

3) utilize the experience of university researchers in the field of air-jet impingement (eg. Dr. Arun Mujumdar at McGill University) for optimizing the design of air-jet nozzles used in drying or heat transfer.

Finally, to assist in getting the radiofrequency and air-jet impingement hybrid applied in industry, it is recommended that a Canadian manufacturer be identified who could manufacture the hybrid.

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Figure 1 - Results from drying tests using air at 20 C.

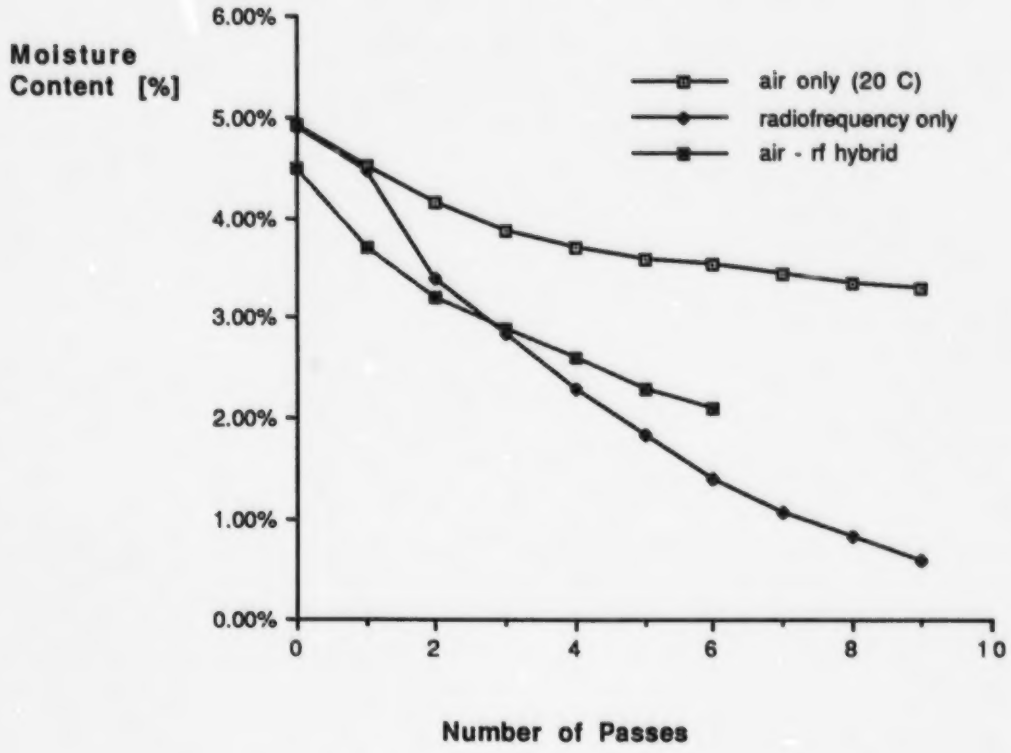


Figure 2 - Results from drying tests using air at 70 C

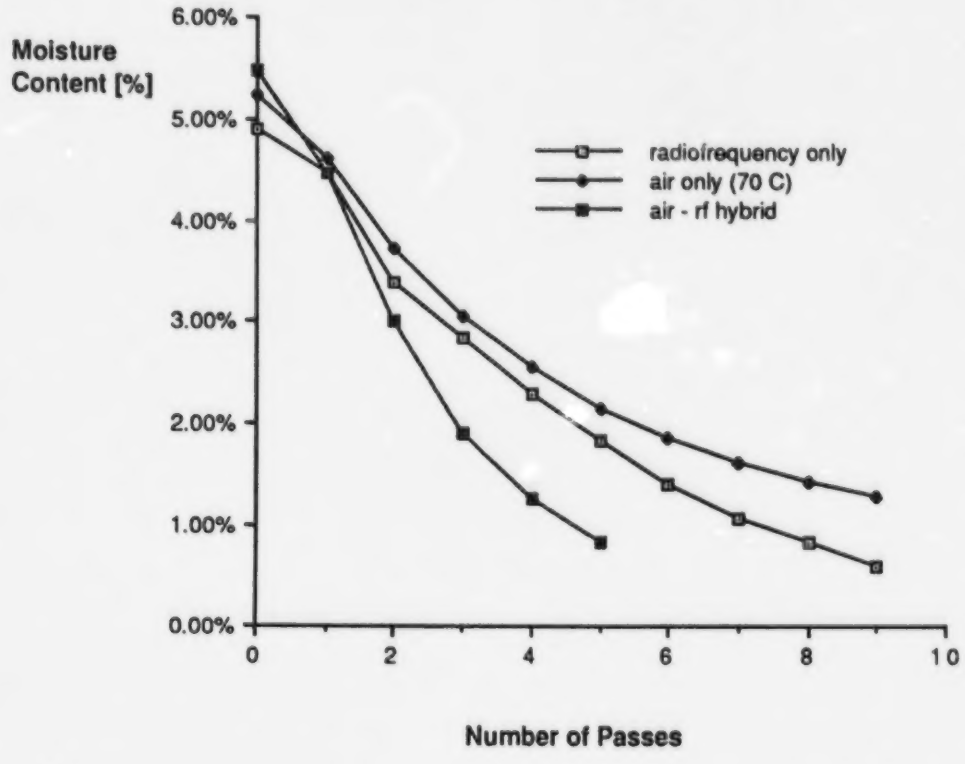
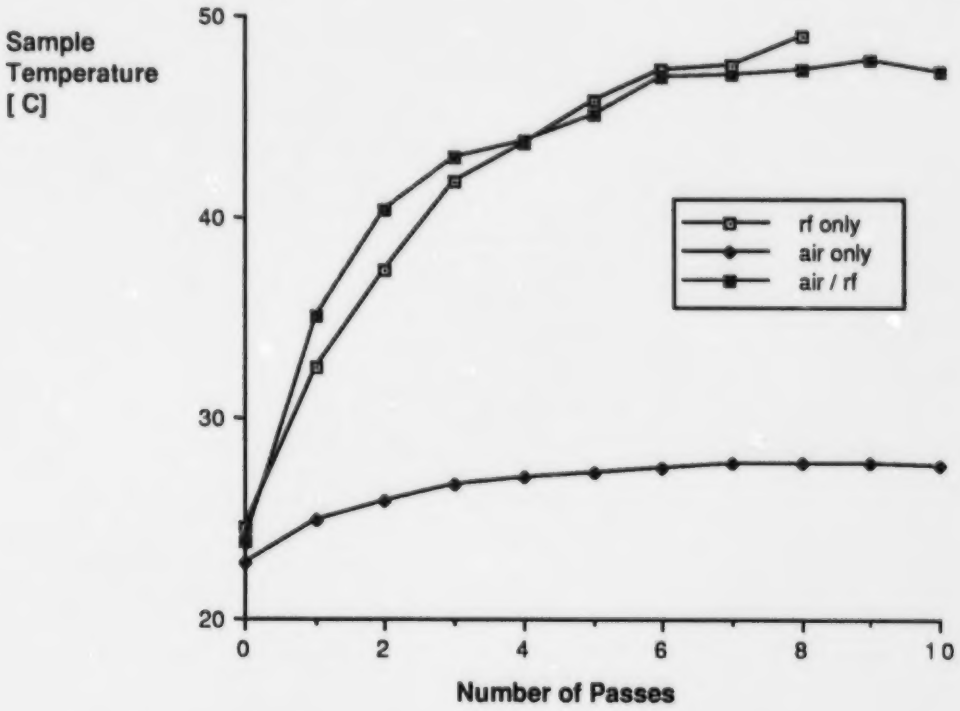


Figure 3 - Results from the heating tests using the radiofrequency/air-jet impingement hybrid with an air-jet temperature of 70 C



Appendix I - Copy of a Memo Outlining Existing and Potential Applications of Dielectric Heating Hybrids

Research Division
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MEMORANDUM

MR. M.R. SANIO
Product Analyst
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May 19, 1989

File: 814.35(P)

Existing and Potential Applications of Dielectric Heating Hybrids

In partial fulfillment of the work outlined in PRF 12-129 (Hybrid Electrotechnologies), a table is attached which lists the various applications for dielectric heating hybrids, according to their respective industry classification.

The table also lists the total electricity consumption in each of the industries. The electrical load information can be used as a starting point to estimate the potential load impact of each application. The approximation of the load impact is necessary as the process energy/electricity is not currently available on an industry and process basis.

Brian Wade

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Attach.

cc: V.J. Sharpe, C25F4
S.J. Oda, KR263

Existing and Potential Applications of Dielectric Heating Hybrids by Industry Classification

SIC	Industry Group	1984 Ontario Total Elect. Cons. for industry Group (GWh)	Hybrid Type: Microwave/ Convection	Microwave/ Vacuum	Microwave/ Infrared	Radiofrequency/ Convection	Radiofrequency/ Vacuum
1011	Meat and meat Products	235	- bacon cooking [1]		- meat and fish roasting [2]		
1031	Canned and preserved fruit & vegetable ind	94	- onion drying [1] - blanching assorted vegetables & fruit [2] - nut roasting [2]	- drying vegetables [2] - drying fruit juice [3]			
1071	Biscuit Industry	31				- biscuit baking and drying [3]	
1072	Bread and Other Bakery Products	79	- bread baking [3]		- bread baking [3]		
1091	Tea and Coffee Ind	13			- coffee drying (with vacuum) [2]		
1092	Dry Pasta Products Industry	10	- pasta drying [1]				
1500	Rubber Products	640	- pre-heating moulded rubber [4] - vulcanization of rubber extrusions [4,5]				
1630	Plastic Film and Sheeting Ind	130	- drying of PVDC coated films [17]				
1700	Leather and Allied	100				- drying leatherboard (air-jet impingement) [11]	
1800	Primary Textiles Ind	621	- textile dye fixation [6]			- textile drying [16]	- textile drying [16]
2500	Wood Industries	528				- lumber drying [12]	- lumber drying [15]
2520	Veneer and Plywood Ind	44 (1980 figure)	- veneer drying (with air jet impingement) [7]			- veneer drying [13] - fibreboard drying (with air-jet impingement) [14]	

SIC	Industry Group	1984 Ontario Total Elect. Cons. for industry Group (GWh)	Hybrid Type				
			Microwave/ Convection	Microwave/ Vacuum	Microwave/ Infrared	Radiofrequency/ Convection	Radiofrequency/ Vacuum
3250	Other Motor Vehicle Parts & Accessories	486	- drying refractory coated foam patterns (evaporative casting process) [8]				
3510	Clay Products Ind	74	- ceramic drying [9]*				
3740	Pharmaceutical & Medicine Ind	108		- drying pharmaceutical products [10]			

* the microwave/convection hybrid installation reduced electricity consumption from 131 kW to 98 kW

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Appendix II - Design of the Radiofrequency / Air-Jet Impingement System

The development of the hybrid system involved changes to the radiofrequency equipment in the lab and in the design and construction of a system of air-jet nozzles to operate in the radiofrequency applicator.

The radiofrequency system used in the hybrid was a 6 kW Strayfield Wiles system with a "stray field" electrode configuration. The main changes to the radiofrequency unit involved:

1) cutting holes in the applicator to pass the compressed air lines into the applicator,

2) making sure there was no additional electromagnetic leakage from the equipment,

3) providing an alternate path for the generator's cooling air since the applicator would be pressurized and thus offer increased resistance to the flow of cooling air, and

4) provide sufficient electrical grounding to the air-jet nozzle system.

The information used to design the air-jet nozzles is listed in Table 1. In Table 1, the conclusions from the literature are listed along with their relevance for the design of the nozzles in the hybrid system.

Table 1 - Design Guidelines for the Air-Jet Impingement Nozzles

	Conclusions from Air-Jet Impingement Literature	Impact on Hybrid Design
1	Spacings of less than 4 inches result in a relatively small increase in heat transfer [ref. 2 pg. 140].	Put the nozzles on 10.2 cm. (4 inch) centers.
2	The heat transfer coefficient reaches a maximum at a nozzle-surface separation to nozzle diameter ratio of 8:1 [ref. 1 page 9, ref. 3 page 106].	For a nozzle-surface separation of 7.62 cm. (3 inches) in the applicator, the nozzle diameter will be 0.952 cm (3/8 in.).
3	Orifice nozzles produce heat transfer rates about 10% higher than contoured nozzles [ref. 5 page 394].	Do not round out the nozzle entrances or exits.
4	Center-line turbulence intensities increase as the ratio of the nozzle length to diameter increases [ref. 5 page 396].	Provide a length to diameter ratio for the nozzles of at least 2:1.

The air-jet system was then constructed and installed in the radiofrequency system as shown in figure 4 (without the end caps on the nozzles). Additionally, fibreglass insulation was installed around the piping to minimize heat loss when heated air was used in the nozzles. The air-jet nozzles were supplied by a 11 kW (15 horsepower) oil and water free compressor, with a 3 kW heater in line with the air-jet system. The compressed air supply had to be free of oil and water so that arcing would not occur in the radiofrequency applicator.

Upon commissioning the equipment, the initial drying results with the air-jet impingement system were disappointing. Therefore changes to the size of the nozzles and the number of nozzles used were made to improve the performance of the system. The nozzle size was adjusted by placing wooden dowels in the copper nozzles, which allowed the nozzle diameter to be changed easily. Additionally, half of the nozzles were blocked on two tests, which has the effect of increasing the velocity of the air-jet and increasing the spacing of the nozzles. The results from brief tests with the different nozzle configurations are shown in Table 2. Based on the results from these tests, a system of 36 nozzles with a diameter of 1.59 mm. (1/16") provided the greatest drying rate and was therefore used in the subsequent heating and drying tests.

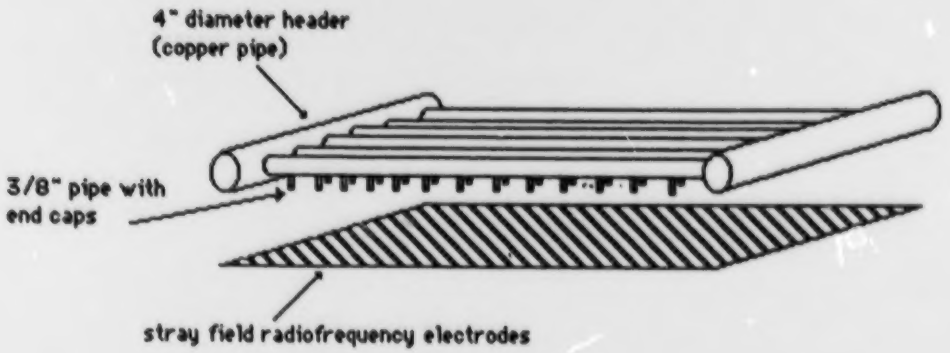
Table 2 - Drying rates with different nozzle configurations

nozzle diameter	Drying Rate (grams/pass) *	
	72 nozzles	36 nozzles
1.59 mm. (1/16")	-----	6.9
3.17 mm. (1/8")	4.9	6.4
4.76 mm. (3/16")	4.0	-----
6.35 mm. (1/4")	6.0	-----
9.52 mm. (3/8")	3.5	-----

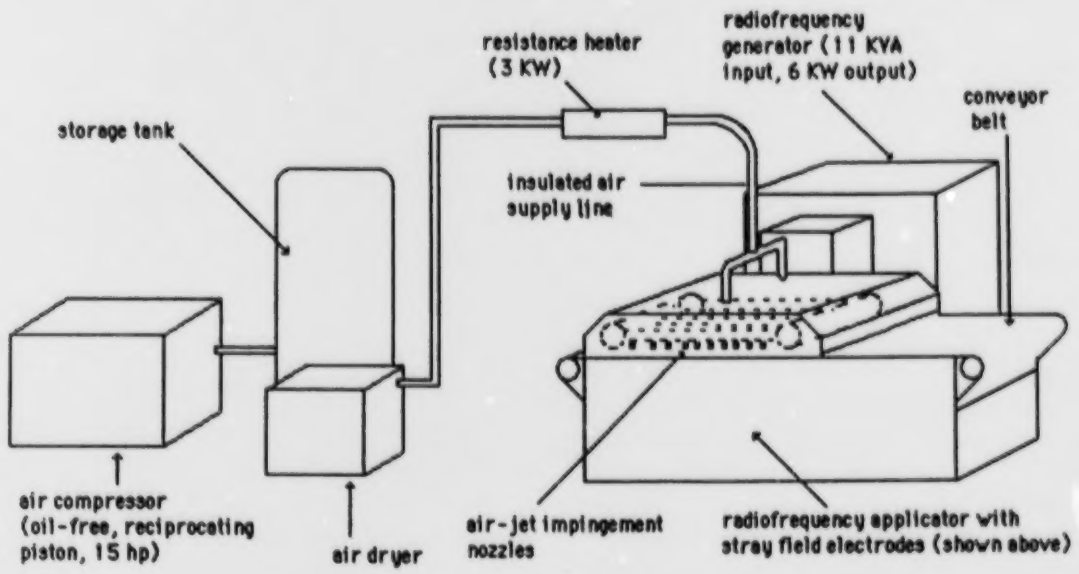
* based on the drying rate over the two passes (1 pass = 15 seconds process time for each side) most closely straddling a moisture content of 100 g., or 4%.

A concern about the results in Table 2 is that the maximum drying rate occurred with a diameter of 1.59 mm (giving a ratio of 48:1 for the nozzle-surface separation to nozzle diameter) and with a nozzle spacing of 20.3 cm. (8 inches). These results contradict the first two design guidelines in Table 2. The most likely explanation for this discrepancy is the degree of turbulence in the air flow. In the literature, the results are usually presented for turbulent flows, while the flows were probably laminar with the larger nozzle diameters and number of nozzles.

Figure 4 - Configuration of the radiofrequency electrodes and air-jet nozzles



(a) location of air-jet nozzles above stray field electrodes



(b) configuration of the total hybrid system

Appendix III - Description of the Lab Tests

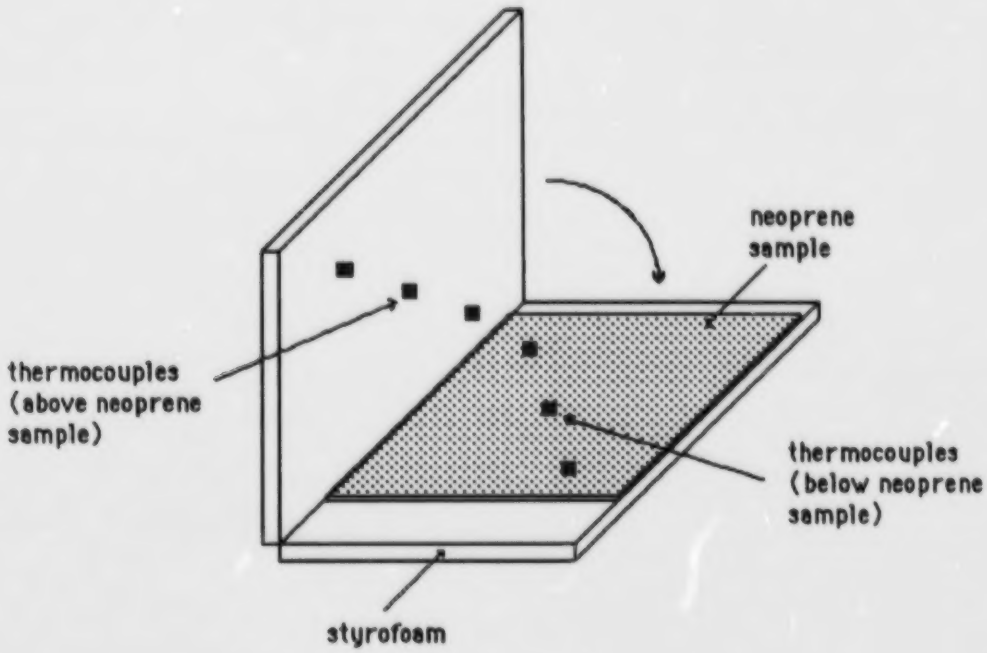
The primary objective of this project was to design and construct a prototype radiofrequency/air-jet impingement hybrid system. However, in order to assess the performance of the system and make recommendations for further development, some brief lab tests were required. Since the primary applications for the radiofrequency/air-jet hybrid are for drying and heat transfer, lab tests were performed for each of these applications.

The drying tests involved drying a 0.006 m x 0.914 m. x 0.61 m. (1/4" x 3' x 2') piece of particle board that was re-wetted for each test. To monitor the drying rate, the weight of the board was monitored before it was wetted, after it was wetted and after each pass through the system being tested. A pass actually consisted of passing the board through the system once, then flipping the board over and passing it through again. The board was flipped so that both sides of the board would be exposed to the system being tested (ie. air-jet only, radiofrequency only, or the hybrid).

For the heat transfer tests, a suitable load had to be found which would not evaporate during the tests (and thus make it difficult to take meaningful measurements), would be compatible with a radiofrequency applicator (eg. not cause any arcing or overloading) and would not be prone to thermal runaway. The best candidate material for this load was found to be a 76.2 cm. x 60.8 cm. x .32 cm. (30" x 24" x 1/8") piece of neoprene.

Instead of actually measuring the heat transferred to the sample, the average sample temperature was used as an indicator of the heat transfer rate. The temperature was measured by placing the sample between two pieces of foam insulation primarily to allow the temperature distribution across the thickness of the sample to even out. The temperature was monitored at six locations on the sample, as shown in Figure 5, and the average of the six measurements was taken as the typical temperature of the sample. As in the drying tests, the sample was flipped during each pass so that both sides of the sample were exposed to the system being tested.

Figure 5 - Thermocouple locations for the heat transfer tests



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